AD-A129 578 IMPROVEMENTS IN F-16 ENGINE RESTART CAPABILITY WITH A SIPU (SUPER INTEGRA..(U) SUNDSTRAND AVIATION MECHANICAL UNIT ROCKFORD IL W G SMITH ET AL. DEC 82 1/1

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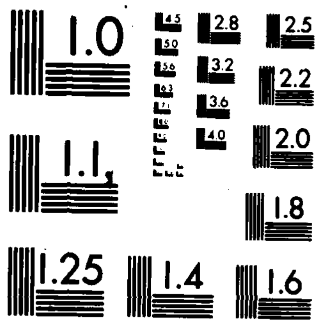

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IMPROVEMENTS IN F-16 ENGINE RESTART CAPABILITY WITH A SIPU

Sundstrand Corporation
Sundstrand Aviation Mechanical Unit
4747 Harrison Avenue
Rockford, IL 61125

DECEMBER 1982

FINAL REPORT FOR PERIOD DECEMBER 1981 - OCTOBER 1982

Approved for Public Release; Distribution Unlimited

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWAL-TR-82-2118	2. GOVT ACCESSION NO. AD-A129 578	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) IMPROVEMENTS IN F-16 ENGINE RESTART CAPABILITY WITH A SIPU		5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT FOR PERIOD DEC 1981 - OCT 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) W. GLEN SMITH RICHARD J. FANDEL		8. CONTRACT OR GRANT NUMBER(s) F33615-82-M-2220
9. PERFORMING ORGANIZATION NAME AND ADDRESS SUNDSTRAND CORPORATION SUNDSTRAND AVIATION MECHANICAL UNIT 4747 HARRISON AVENUE ROCKFORD, IL 61125		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 3145 01 45
11. CONTROLLING OFFICE NAME AND ADDRESS AERO PROPULSION LABORATORY (AFWAL/PCOS) AIR FORCE WRIGHT AERONAUTICAL LABORATORIES (AFSC) WRIGHT PATTERSON AFB, OHIO 45433		12. REPORT DATE DECEMBER 1982
		13. NUMBER OF PAGES 40
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SUPER INTEGRATED POWER UNIT
AIRCRAFT START SYSTEMS
AUXILIARY POWER

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The F-16 main engine inflight restart capability would be greatly enhanced by utilizing a Super Integrated Power Unit (SIPU). Because the available starter power remains constant at all altitudes, the engine can be motored at relatively high rotative speeds, providing for rapid acceleration to a self sustaining condition after relight. This reduced start time plus a multiple start capability, reduces altitude loss and increases safety during combat. The SIPU concept expands the airstart window and allows the pilot to assume a "best range"

continued...

20. ABSTRACT - continued

-flight attitude which increases both time and range by up to 35% in the event the engine is not able to start.

PREFACE

The Super Integrated Power Unit (SIPU) is a novel idea for future auxiliary/emergency power units which would be capable of satisfying the numerous power requirements of today's high technology aircraft.

The program was initiated by Dr. B.L. McFadden (AFWAL/POOS) to obtain unbiased and realistic data concerning the advantages/disadvantages of using a SIPU for main engine starting. Of primary concern are starts at altitudes above 20,000 ft. where present jet fuel starters (altitude sensitive) are subject to rapid reductions in output power capability. The SIPU is capable of maintaining 100% power at all altitudes which could extend the present start envelope to greater altitudes. The study evaluates the SIPU concept to estimate the reduction in both time and altitude required to perform a main engine start. The F-16 was selected as a current example of combat aircraft which would benefit from this system.

This study was conducted with the cooperation of General Dynamics/Fort Worth, Pratt and Whitney/West Palm Beach and General Electric/Evendale. The contribution of engine and aircraft information by these companies made it possible for the analysis to provide a more accurate evaluation of Super Integrated Power Unit effectiveness as applied to the F-16 aircraft. The SIPU concept, considered in this study, is being developed by Rocketdyne Division of Rockwell International Company under a seperate contract with the Aero Propulsion Lab (AFWAL-POOS).

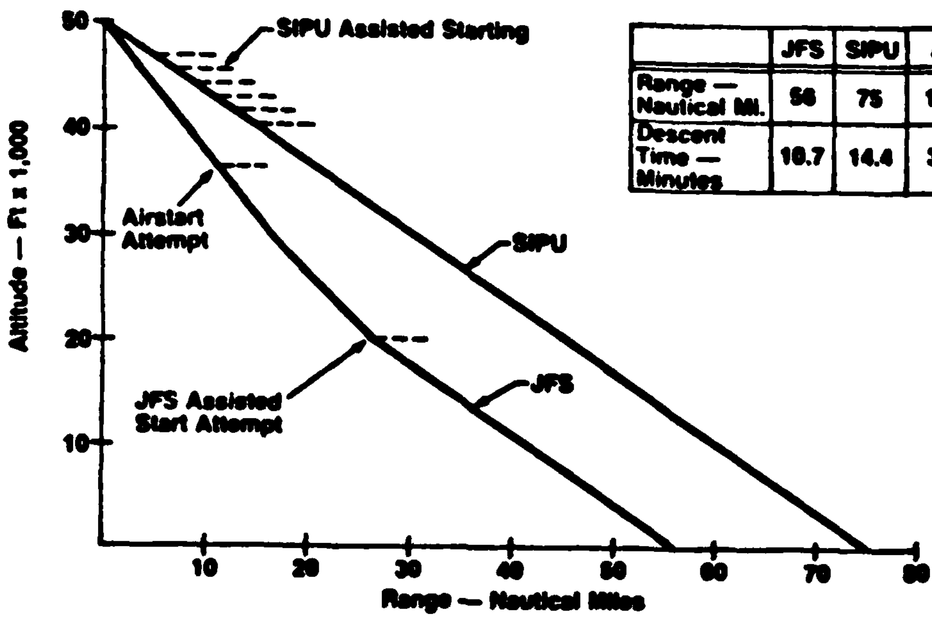
TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

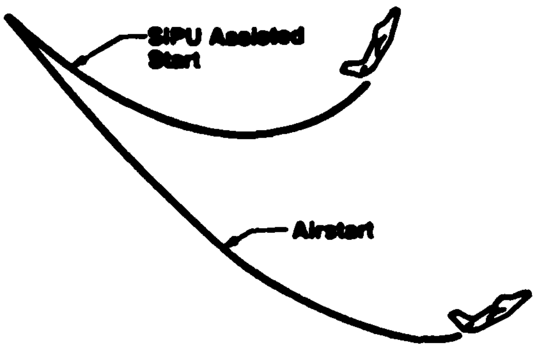
SUMMARY

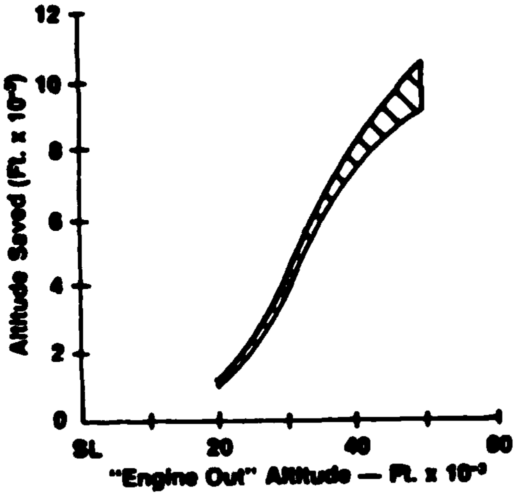
A SIPU equipped aircraft maintains 100% starter power at all altitudes. This eliminates the need for rapid descent to enter an airstart window and allows the pilot to adopt a simplified glidepath during a start attempt. In an engine-out condition, the aircraft can assume a "best range" flight attitude regardless of the altitude at which the engine malfunction occurs. This feature optimizes the glide range and substantially increases descent time if all engine start attempts are unsuccessful. The pilot has additional time to determine the reason for engine failure and an increased chance of restarting the engine, finding a suitable landing site or reaching safe territory before ejecting.

In addition, a SIPU provides faster engine starts, which is equivalent to a reduction in altitude lost during a start. At an initial altitude of 50 K ft., there is a 35% increase in range if the engine does not start or a 10,000 ft. altitude saving during a successful start. These advantages are shown in the figures below and are included in the following list of benefits.



	JFS	SIPU	Δ	%
Range — Nautical Mi.	56	75	19	34
Descent Time — Minutes	10.7	14.4	3.7	35





NOTE: BANDWIDTH IS CAUSED BY THE DIFFERENCE IN START TIMES AFTER VARIOUS ENGINE MALFUNCTIONS

The following list highlights the enhancement of F-16 capabilities through use of a Super Integrated Power Unit. Estimations consider flight altitudes from 25K ft to 50K ft.

- Constant starter power at all altitudes (shorter start times)
- Ability to motor unfired engine at 43%-48% RPM
- Simplifies Pilot's duties
- Reduces airstart time (up to 20 seconds)
- Reduces restart altitude loss (as much as 10,000 ft.)
- Increases glide time and distance (up to 35%)
- Better engine-out chance to find landing site or reach safe territory (diving is not required for airstarting the main engine)
- Reduces incapacitated time
- Possible combat safety enhancement
- More aircraft return under own power

This system, while described for the F-16, is beneficial for all types of aircraft. Using the SIPU concept, a more versatile secondary power device is available to the high performance aircraft designer.

I INTRODUCTION

With each new generation of military aircraft, it is becoming more desirable to be less dependent on ground power. Primary and secondary emergency power requirements are growing along with the need for increased safety. This trend toward total self sufficiency necessitates onboard systems capable of meeting the following requirements:

. electrical, hydraulic and pneumatic power for ground checkout and standby
. main engine starting (all altitude)
. primary and emergency electrical and hydraulic power (all altitude)

Existing systems are not able to satisfy all of the above requirements. However, the "Super Integrated Power Unit" is a new concept which would be able to provide complete system capability.

The following table identifies various power sources and describes their function. The systems are listed in the order of increasing capability.

	POWER SOURCE	SYSTEM	CAPABILITY
ATS	Air Turbine Starter (Ground Cart Power)	High pressure air is used to power an air turbine which drives through a gear box to rotate and start the main engine.	Ground Starting/Motoring
JFS	Jet Fuel Starter	An air breathing gas turbine engine (performance degrades with altitude), which is usually started using on-board hydraulic accumulators. It drives through a gear-box to rotate and start the main engine.	ATS + -Self sufficient operation for engine starting/motoring -Inflight start assist to 20K.ft.
APU	Auxiliary Power Unit	A JFS, which can be mechanically disengaged from the main engine PTO shaft, to provide standby and emergency electrical and hydraulic power independent of main engine operation	ATS + JFS + -Ground checkout and alert power. -Inflight emergency power to 20K.ft.
SIPU	Super Integrated Power Unit	A non-airbreathing gas generator is added to the APU. This gas generator can provide 100% power at all altitudes.	ATS + JFS + APU + -Inflight start assist and emergency power at any altitude. -Temperature independent APU starting using the gas generator.

Typically, all engine start and emergency power requirements below 20,000 ft (20K ft.) can be satisfied using an air breathing-JP 4 gas turbine engine. At altitudes above 20K ft, the output power from this type of gas turbine rapidly deteriorates (lower air density) and is no longer able to satisfy engine start and emergency power requirements. The air breathing engine could be oversized, making it run at part load (poor efficiency) for normal operation. Weight, volume and controls would become critical and a larger hydraulic system would be required for initial starting. A more sophisticated design, similar to a standard jet engine, could also be used for increased power and easier starting at higher altitudes. But, because this unit would be larger, heavier and expensive, it too is an unlikely candidate for all altitude capability.

Adequate power for all conditions can be provided through a gas generating system which uses fuel and a stored oxidizer. JP4 and liquid oxygen appear to be an ideal fuel-oxidizer combination when considering performance and logistics.

This additional energy source can be integrated into an existing air breathing gas turbine power unit and evolve into a "Super Integrated Power Unit". In addition to providing sufficient power to meet the requirements outlined above,the optimum SIPU has inherent flexibility as shown below:

- OPTIMUM SIPU PERFORMS:
  - JFS/APU STARTS WITH GAS GENERATOR
  - GROUND SECONDARY POWER GENERATION WITH APU (AIR-BREATHING)
    - ELECTRICAL, HYDRAULIC AND PNEUMATIC
  - MAIN ENGINE GROUND STARTS
  - EMERGENCY POWER IN 3 MODES:
    - GAS GENERATOR
    - MAIN ENGINE BLEED AIR
    - AIR-BREATHING (TO 20 K FT)
  - MAIN ENGINE RESTART IN 2 MODES:
    - GAS GENERATOR
    - AIR-BREATHING (TO 20 K FT)

Figure 1 is a schematic of a typical SIPU system. A single turbine wheel with two separate nozzle sets (different drive gases) is used to power the unit. The LOX/JP4 gas generator is always used to start the unit, having the advantage of checking out the LOX/JP4 system each time an engine start is made or auxiliary/emergency power is required. During start-up, the aircraft accessories are brought up to speed with the unit. The hydroviscous clutch is then closed to accelerate the torque converter to maximum torque and start the engine. At the designated (PTO) speed, starter output torque has dropped off to zero and the starter cuts out. The engine continues to accelerate under its own power, overrunning both the torque converter (clutch C) and the power unit (clutch A) while engaging clutch B to drive the accessories. Emergency/auxiliary power is provided by leaving the hydroviscous clutch open. When the APU is operating in the gas generator or bleed air mode, the compressor can be either aerodynamically or mechanically isolated from the turbine to maximize performance by reducing the compressor losses.

II SCOPE OF STUDY

1. STARTER TORQUE

The engine start analysis performed in this study uses operating characteristics of the existing F-16 Jet Fuel Starter (JFS). The maximum available output torque is that which saturates the system torque converter. Figure 2. compares both SIPU and JFS Output power capability. The maximum available torque applies to SIPU starts at all altitudes and to JFS starts at Sea Level. Because the JFS is an airbreathing gas turbine, the lower air density at higher altitudes decreases the output power.

2. AIRCRAFT ACCESSORIES

During an engine start, the starter must overcome engine drag torque plus aircraft accessory torque. Figure 3 is a plot of specification data for hydraulic and electrical accessories with respect to PTO speed. The specification data was modified slightly for a computer model which calculates engine acceleration vs. time during a main engine start. The abrupt changes in accessory torque level result from increases/decreases in demand for hydraulic and electrical power. Short duration spikes in torque are not modeled because the system moment of inertia damps out any effect on core acceleration.

3. ENGINE-STARTER TORQUE MARGIN

Figure 4 shows the SIPU starter torque curve included with two engine torque curves. The engine data is from flight testing and includes the aircraft accessories. Because the aircraft has a 250 knot indicated air speed (KIAS), the engine will windmill at $\approx$ 1000 rpm.(PTO). Higher rotative speeds require positive input torque to accelerate the core. When the engine fires, at a PTO speed slightly greater than 3000 rpm., the drag torque rapidly drops and becomes negative, representing engine self acceleration torque. Using the differential torque between starter and engine for added acceleration, engine rpm increases until idle speed is reached. At this point, fuel flow is decreased and acceleration torque returns to 0. The starter torque decreases as speed increases, reaching 0 at $\approx$ 8,000 rpm.(PTO). This point is referred to as the "starter cut-out speed". Note also, that there is little change in engine firing speed as altitude varies. Therefore, a two-stage gear box is not necessary to rotate the main engine to higher speeds for light-off.

4. WINDMILLING ENGINE-START TIMES

Engine start times from a windmilling (cool engine) condition are calculated using the available acceleration torque, engine drag torque, accessory drag torque and engine core moment of inertia. A manual integration with respect to time, using the equation $\alpha = T/I$ where α = core acceleration, T = applied torque and I = core moment of inertia results in incremental acceleration rates which are plotted in Figures 5 and 6.

Figure 5 compares JFS and SIPU main engine start times for an aircraft gliding at Mach .4 with the engine windmilling. This causes the engine acceleration to begin at 1000 + rpm. The difference in initial time delay is due to the slower starting airbreathing gas turbine (JFS), taking up to 17 sec. longer to develop full output torque. Greater SIPU PTO starting torque provides faster engine acceleration saving an additional 13 sec of engine start time.

Figure 6 compares start times for the P&W F100 engine with the G.E. F101 engine using engine torque data from flight tests (P&W) and facility tests (G.E.). The difference in start time is mainly the result of a higher G.E. engine core moment of inertia.

5. F-16 AIRSTARTS

An engine malfunction (high and low power stagnation stall or flameout) requires a restart attempt as soon as possible. At altitudes above 20K ft, the pilot follows a procedure for airstarting during spin-down. The following sequence of pilot operations is recommended to maximize airstart success.

(a) Throttle to "off" position	-pilot must minimize time in getting throttle to "off" when an engine malfunction is detected.
(b) Engine temperature below 700°C	-The fan turbine inlet temperature should be below 700°C when initiating an airstart or a hot start will occur.
(c) Engine RPM between 25% and 40%	-The engine speed should be between 25% and 40% before making an airstart. Even if the engine temperature drops below 700°C, the pilot must wait for the rpm. to reach 40%.
(d) Throttle to "Midrange" in airstart window	-Pilot advances the throttle to "midrange" after the airstart window requirements have been satisfied (b and c above). The throttle is placed in midrange if RPM reaches 25% regardless of fan turbine inlet temperature.

(e) Light-off occurs within 15 sec. -After advancing the throttle to midrange, the engine support systems have automatic timing functions which fire the engine within 15 sec.

Figure 7 shows the F-16 engine out descent path and operating envelopes for JFS operation, airstart and SIPU assist starts. During an airstart attempt, it is recommended that the pilot follow a specific flight path, which varies depending on the initial altitude. To minimize energy loss while reducing time to reach the "unified fuel control" airstart envelope, a 30° dive to 40K ft. is recommended. Once inside the start envelope, 300 KIAS must be maintained to 30K ft. followed by 250 KIAS to 20K ft. If an airstart has not been successful to this point, the JFS is used to attempt a restart. The glide speed affects the engine spin down and cool down rate and is prescribed to improve the airstart window.

NOTE: The following analysis, which shows the SIPU advantages in both altitude saving and range, assumes a 300 KIAS descent for airstarting at all altitudes between 50K and 30K ft. The 300 KIAS has a better glide ratio than a 30° dive which gives the unassisted airstart longer range. Because the lack of start data makes actual start times difficult to predict, the time saved is assumed to be the same for all altitudes (20K to 50K ft.). The spool down information available suggests that a 50K ft. start time may take about 5 sec. longer than at 25K ft. after an engine flameout. After a high or low power stagnation, start times are affected less by higher altitudes because the start system is available for starting before the FTIT enters the 700°C temperature band.

Because a SIPU equipped aircraft provides a constant level of starter power, independent of altitude, there is no need for a rapid descent to enter a start envelope. Therefore, a "best range" glide slope can be maintained at all times in an engine-out condition, maximizing glide range and increasing descent time in the event engine restarting is unsuccessful. Figures 8, 9 & 10 graphically illustrate significant increases in time and distance when the initial altitude is 50, 40 or 30K ft. The maximum saving is ≈ 35% which gives the pilot time to determine the reason for engine failure and increases the chance of restarting the engine, finding a suitable landing site or reaching safe territory before ejecting.

6. ENGINE MALFUNCTIONS

Figures 11, 12 & 13 show three engine malfunction situations after which an airstart would be attempted. In Figures 11 & 12, after a high or low power stagnation stall, the engine temperature continues to rise until the pilot detects a problem and moves the throttle to the "off" position. In both cases, the airstart window does not begin until 700°C is reached and ends at the 25% speed point, resulting in a small airstart window. Figure 13 shows the "flameout" condition, where temperature drops rapidly and the pilot must wait until speed reaches 40% before advancing the throttle. In this case, the start window is limited by the 40% to 25% speed band.

7. AIRSTART

Figure 14 shows a relatively small effect of altitude on both engine cool down and spin down rates for the "flameout" condition at 250 KIAS. FTIT (Fan Turbine Inlet Temperature) is always down to 700°C in the same time, independent of airspeed. In the 25K ft. to 35K ft. altitude range, there is approximately a 2 sec. difference in the time taken to reach 50% RPM. Because there is a relatively small variance in high altitude spool down rates, and airstart data is available for only one condition, this study assumes that start times are typical for the higher altitudes being considered.

Figure 15 is an example of a "High Power Stagnation Airstart" with engine temperature and rpm plotted as a function of time. By the time the pilot is sure there is an engine problem, and moves the throttle to "off", the temperature increases from 900°C to 1000°C. After 15 sec., the temperature has dropped to 700°C and the throttle is advanced to "midrange". Speed continues to sag while waiting a maximum of 15 seconds for the engine to "light-off". After "light-off", the engine slowly accelerates to stabilize at part power

8. SIPU ASSIST AIRSTART

Figure 16 shows graphically how a SIPU starter motors the main engine. Time "0" in this figure is when the SIPU is started by the pilot and is equivalent to point (1) in Figures 17 & 18 where FTIT rises and the throttle is moved to "cut-off". In all cases, the SIPU is up to speed (51% PTO speed) before the engine decelerates to that level with the PTO shaft overrunning the one way starter clutch. The engine decelerates to the starter idle speed where a fuel control system senses engine load and applies full starter power. The starter and engine, now operating at the same speed, will continue to decelerate until the starter output torque matches the motoring torque required by an unfired engine. This speed is between 43% and 48% for a 25K to 50K altitude range. For the purpose of this study, a motoring speed of 47% (40K ft.) was used for analyzing SIPU effects.

The ability to maintain a "best range" glide speed while motoring the engine at a constant speed, reduces pilot activity by making start procedures less involved. The differences are demonstrated in the start comparison below.

1. Identifies "Stagnation" or "Flame Out"

2. Moves Throttle to "Cut-Off" Position	2. Moves Throttle to "Cut Off" Position . Starts SIPU
3. Flys "Airstart" Glide Path	3. Flys 210 kt. Glide
4. Waits Until Engine - . RPM is Between 40% & 25% . Temp. is Below 700°C.	4. Motors Engine Until Temp. is Below 700°C.
5. Moves Throttle to "Midrange" When - . Both Item 4. Conditions Are Met . RPM Reaches 25%. Regardless of Temp.	5. Moves Throttle to "Midrange"

6. Light-Off Occurs Within 15 Seconds

7. Starts "JFS" at 20 k ft. if Necessary

Figures 17, 18, & 19 are examples of the estimated differences between a normal airstart and a SIPU assisted airstart. Only the "High Power Stagnation" case will be described for reader clarification. As the starter supports the engine and slows the deceleration rate, the temperature begins to drop more rapidly due to the higher airflow in a motored engine, reaching 700°C several seconds before an unassisted start. Light-off occurs within 15 sec after the throttle is placed in the "mid-range" position. A large amount of time is saved after light-off because the engine does not have to accelerate from 25% to 47% speed. The total airstart time saving is 21 seconds. In the low power stagnation and flameout cases, the time saving is 19 seconds and 20 seconds respectively.

At lower altitudes, where engine restart time is critical, JFS and SIPU output power are comparable. Therefore, the difference in time to reach maximum starter torque will have the major effect on engine start time. The 22 sec. JFS start time (20K ft.) reduces to ≈ 12 sec. at the lower flight levels (3,000 ft.). This results in a 7 sec. SIPU/JFS time difference which would benefit a restart after Flameout by saving ≈ 300 ft. There would be no SIPU advantage after a High or Low Power Stagnation because both start systems reach full output power before the main engine reaches 700°C.

9. SIPU ASSISTED AIRSTART-ALTITUDE SAVINGS

Figure 20 contains descent rates for various flight conditions. The information shown results from altitude, distance and velocity data contained in Figures 8, 9 & 10. The descent rates for the 300 KIAS condition from 50K to 30K ft. are much greater than rates at 210 KIAS due to the higher velocity combined with a much steeper glide angle.

Using this rate of descent information, the reduction in start times (Figures 17, 18 & 19) translate directly into altitude savings. Figure 21 shows the altitude saved if the engine malfunction occurs between 50K, and 20K ft. The altitude saved (band width), depends on which of the three engine malfunctions made an airstart necessary.

A maximum of 10,500 ft. can be saved if the initial altitude is 50K ft., and a minimum of ≈ 1000 ft. at 20K ft. Both start time and descent rate contribute to the difference in altitude lost between a SIPU start and an airstart.

10. F-16 ENGINE START SYSTEM MODIFICATIONS

The mechanical arrangement for the production F-16 Engine Start System is shown in Figure 22. Modifications to this arrangement for implementation of optimum SIPU capability are shown in Figure 23.

The Jet Fuel Starter (JFS) is replaced by the Super Integrated Power Unit (SIPU). The hydraulic start motor (HSM) and its overrunning clutch (ORC) would be removed because the LOX/JP-4 gas generator would start the SIPU in the air breathing mode. A SIPU driven centrifugal scavenge pump would be added to provide pressurized oil to the SIPU driven lube pump for high altitude operation. Jackshaft gearing and two overrunning clutches would be added between the SIPU and accessory geartrains allowing the accessories to be powered by the SIPU without driving the PTO shaft. Accessory power can also be provided while simultaneously starting the main engine through the clutch and torque converters. These changes would require some added gearbox space for implementation, however, over 80% of the production gearbox hardware would remain common.

III CONCLUSIONS

The ability to provide main engine start assist at all altitudes has greater benefits than simply increasing the altitude at which an engine can be started. Currently, the F-16 has assisted starting capability to 20K ft. Above this altitude the pilot can only perform an airstart by following a procedure which "catches and fires" the engine during spin-down. Engine speed and temperature considerations restrict the "air-start window" and limit the number of start attempts. Failure of the engine to start, forces the pilot to descend to 20K ft more rapidly to allow use of the Jet Fuel Start (JFS) for a main engine start.

The availability of 100% starter power (SIPU) at all altitudes eliminates the need for the aircraft to enter a specific airstart envelope. This permits the pilot to put the aircraft in a best range attitude which maximizes range and increases descent time (as much as 35% at 50K ft. alt.) if all start attempts are unsuccessful. The SIPU power system also enables the starter to be up to speed and catch the "dead" engine as it spools down. The starter can then motor the unfired engine until it is cool enough to allow an assisted start attempt. Because the engine is motored at a constant speed, a significant amount of start time can be saved (as much as 35%) by not having to accelerate the engine from a low rpm condition. The reduced start times translate directly into savings of altitude (1,000 ft. to 10,500 ft., starting at 20K ft. and 50K ft. alt.). At lower start altitudes, the amount of altitude saved is reduced. At 5K ft., a SIPU/JFS start time comparison (both units turned on after the same elapsed time) shows a SIPU start saving approximately 300 ft. after a flameout, and almost no saving for the high and low power stagnation conditions.

Pratt & Whitney, the engine manufacturer, believes the present "UFC" controlled engine should be capable of starting at the higher motoring speeds referred to in the text. However, if a change in fuel scheduling is required for this type of start, the new Digital Electronic Engine Control system "DEEC" can be easily programmed for the added capability. In either case, a test program would be initiated to verify adequate engine start capability at rotative speeds greater than 40% rpm.

IV RECOMMENDATIONS

Study results show definite advantages in using a SIPU for high altitude emergency power and engine starting. Therefore, additional time should be spent designing a system package in sufficient detail to optimize performance, size and weight for a given set of conditions. Also, a study in conjunction with the airframer should be performed to determine the best method of SIPU installation in future aircraft and the possibility of prototype testing on an existing F-16. An attrition rate analysis (aircraft and pilot) should be made to estimate the number of aircraft, in a given period, which could avoid crashing by using a SIPU. Consideration would be given to extended engine-out range, faster starts during combat and using a few hundred feet less altitude during a low altitude start.

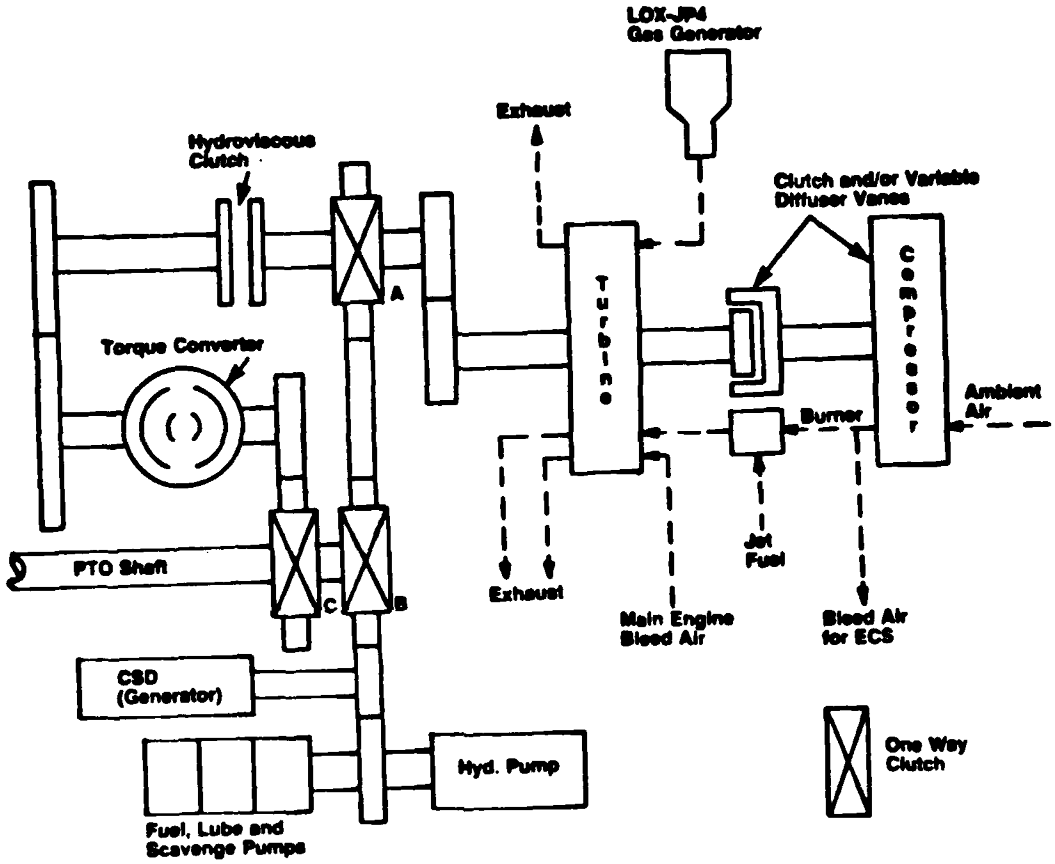


FIGURE 1

TYPICAL SIPU SYSTEM

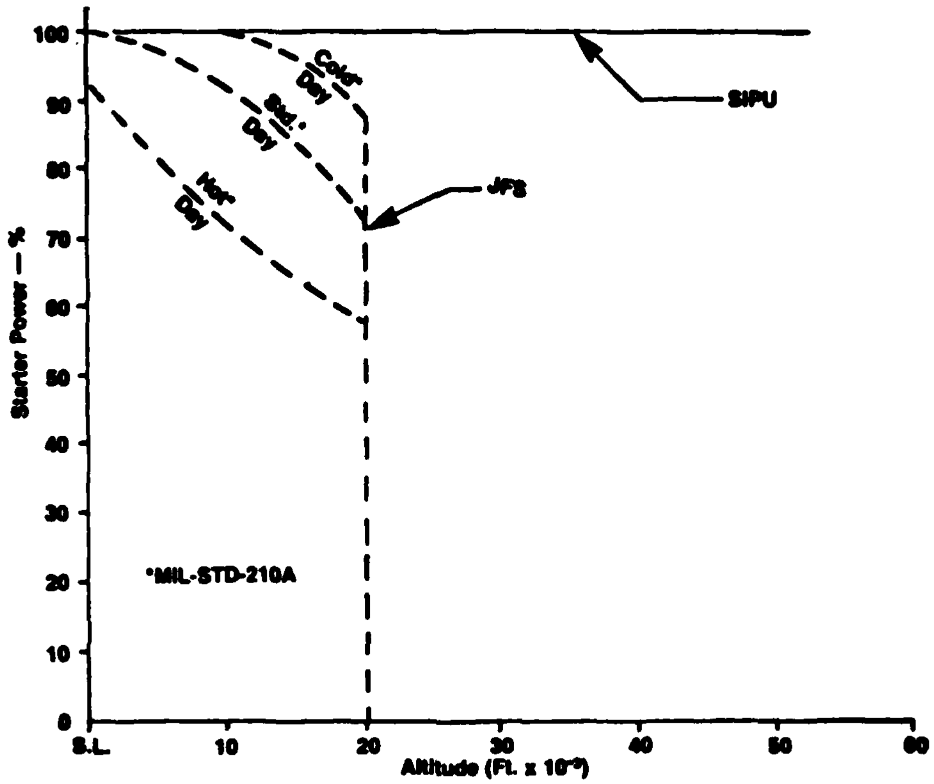


FIGURE 2

SIPU/JFS OUTPUT POWER COMPARISON

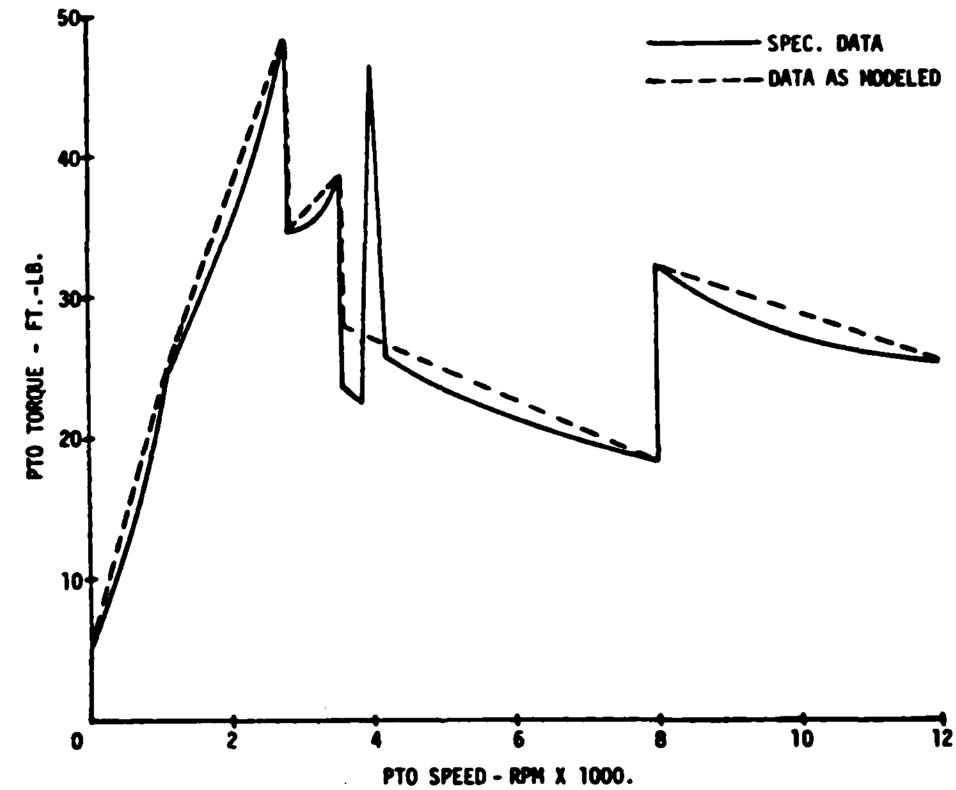


FIGURE 3

AIRCRAFT ACCESSORY DRAG TORQUE (F-16)

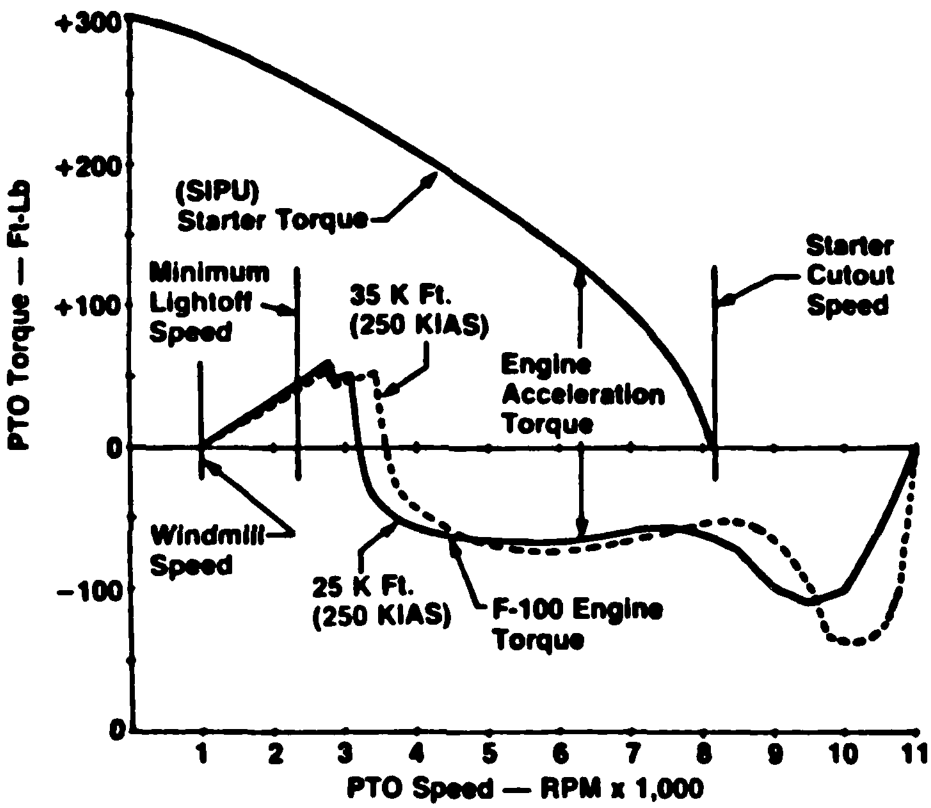


FIGURE 4

SIPU STARTER & ENGINE TORQUE vs. PTO SPEED

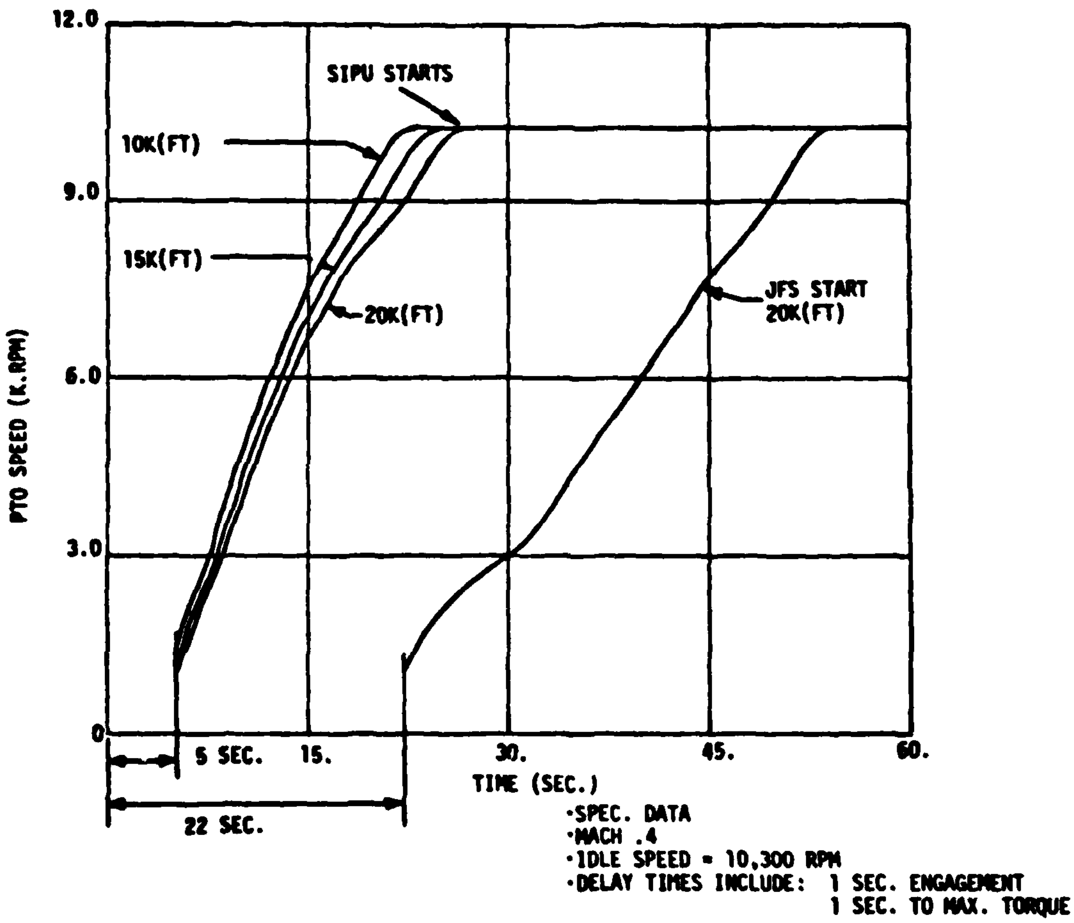


FIGURE 5

SIPU/JFS WINDMILLING START COMPARISON

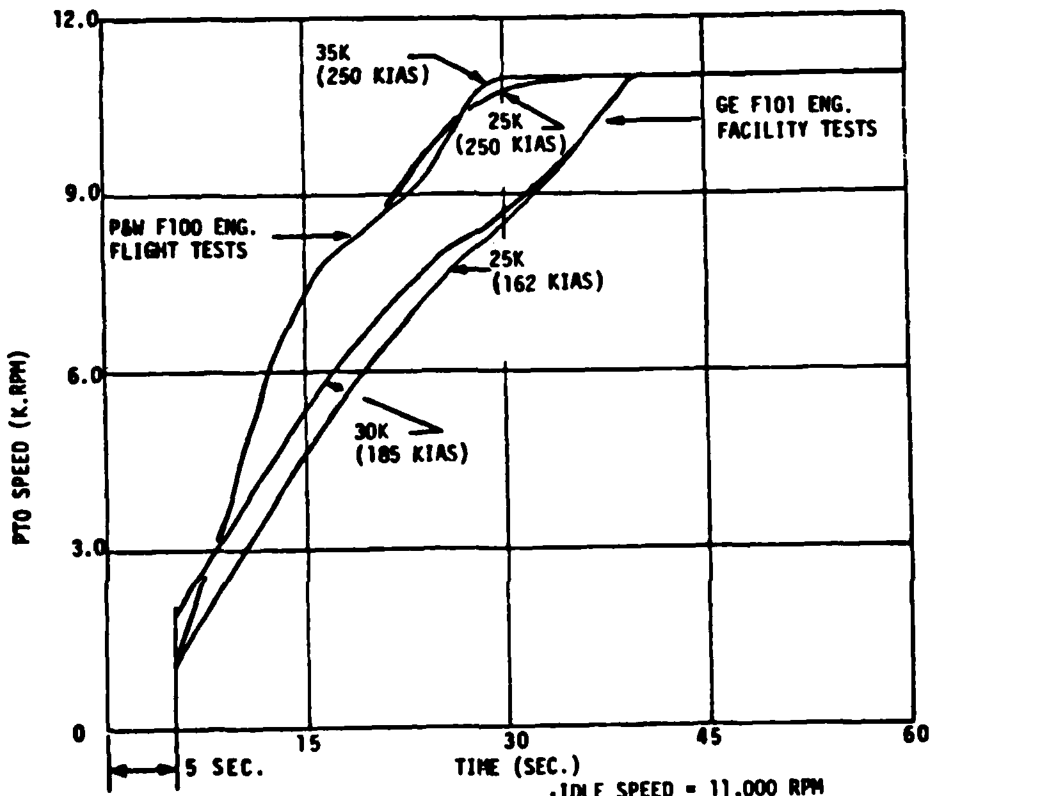


FIGURE 6

SIPU START TIMES vs. PTO SPEED (WINDMILLING ENGINE)

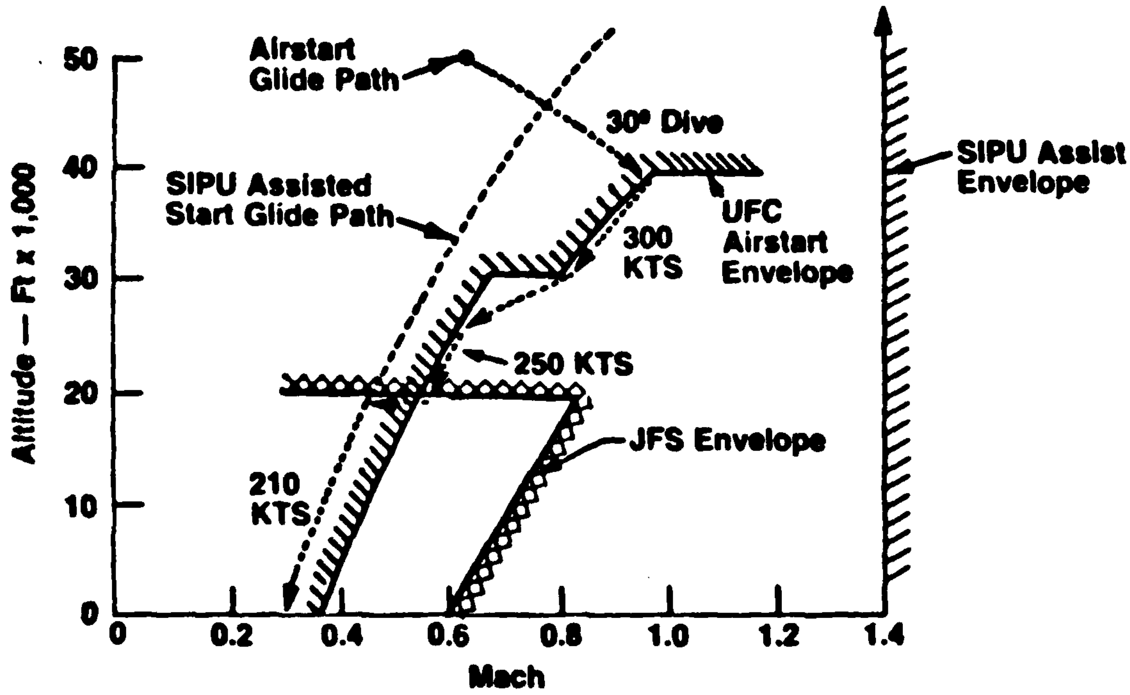
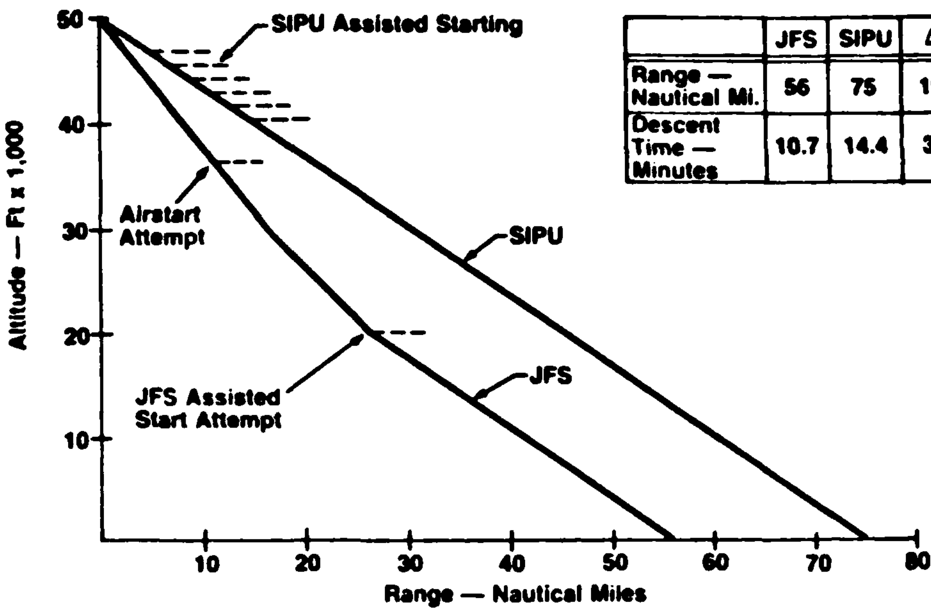


FIGURE 7

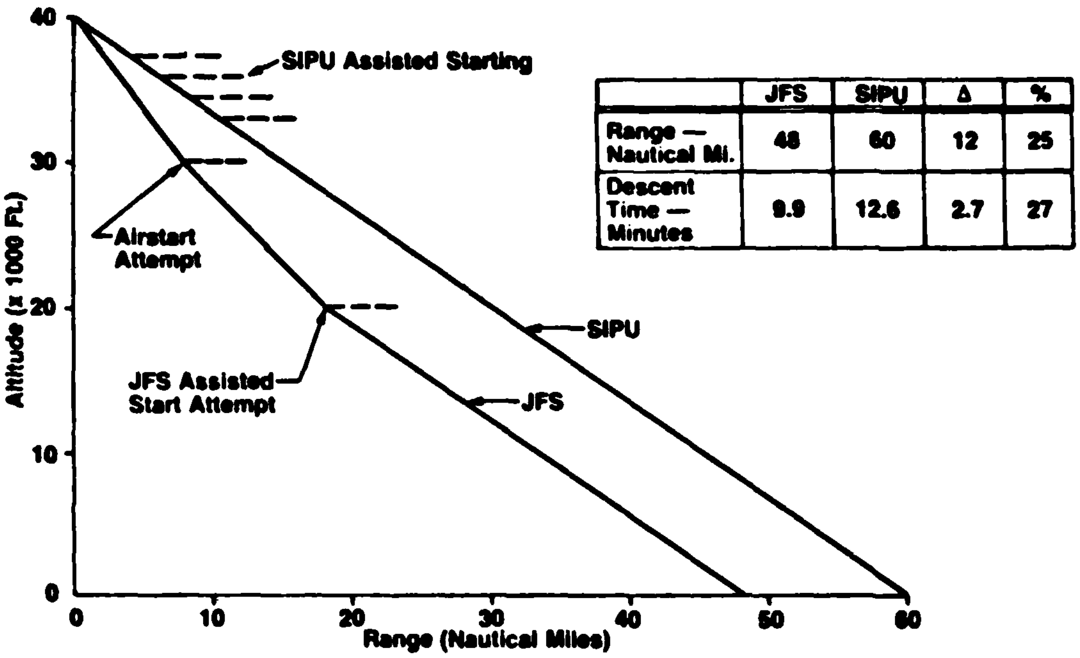
ENGINE OUT DESCENT



	JFS	SIPU	Δ	%
Range — Nautical Mi.	56	75	19	34
Descent Time — Minutes	10.7	14.4	3.7	35

FIGURE 8

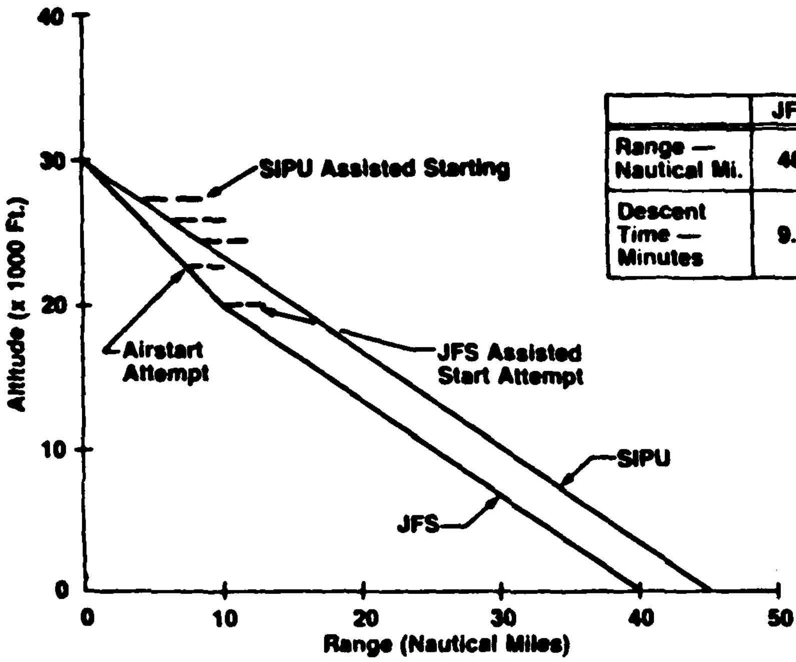
SIPU/AIRSTART (JFS) - ENGINE OUT DESCENT (50 K.ft.)



	JFS	SIPU	Δ	%
Range — Nautical Mi.	48	60	12	25
Descent Time — Minutes	9.9	12.6	2.7	27

FIGURE 9

SIPU/AIRSTART (JFS) - ENGINE OUT DESCENT (40 K.ft.)



	JFS	SIPU	Δ	%
Range — Nautical Mi.	40	45	5	12.5
Descent Time — Minutes	9.0	10.3	1.3	14

FIGURE 10

SIPU/AIRSTART (JFS) - ENGINE OUT DESCENT (30 K.ft.)

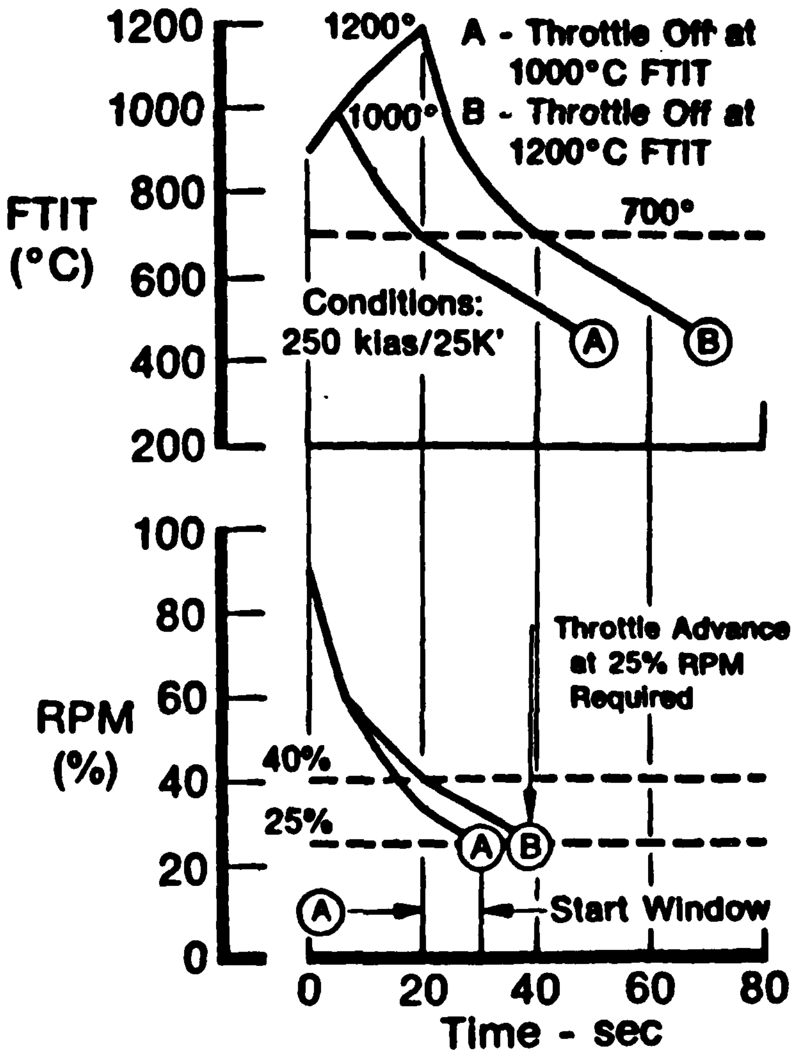


FIGURE 11

AIRSTARTING AFTER HIGH POWER STAGNATION

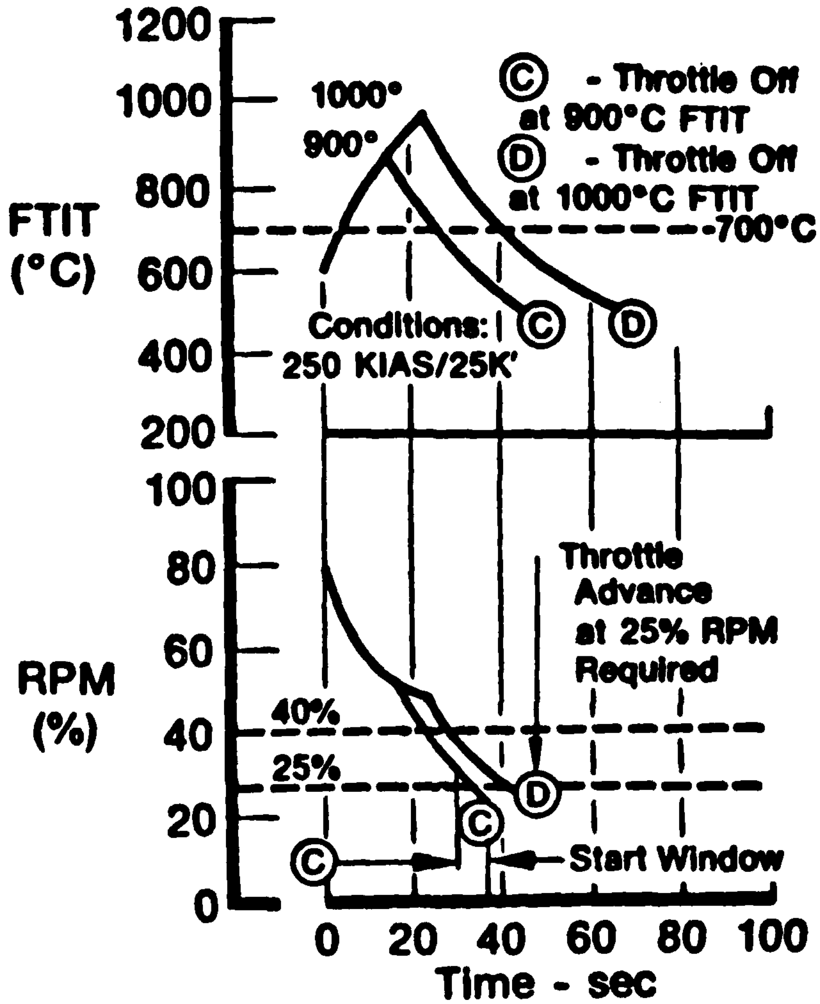


FIGURE 12

AIRSTARTING AFTER LOW POWER STAGNATION

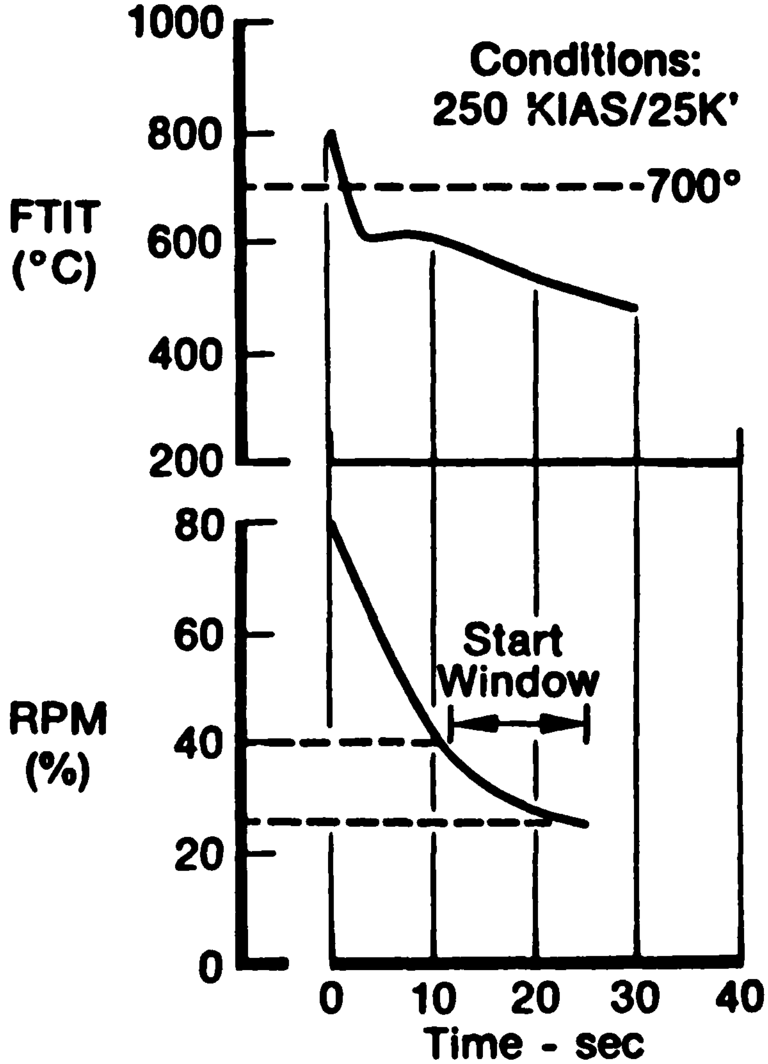


FIGURE 13

AIRSTARTING AFTER FLAMEOUT

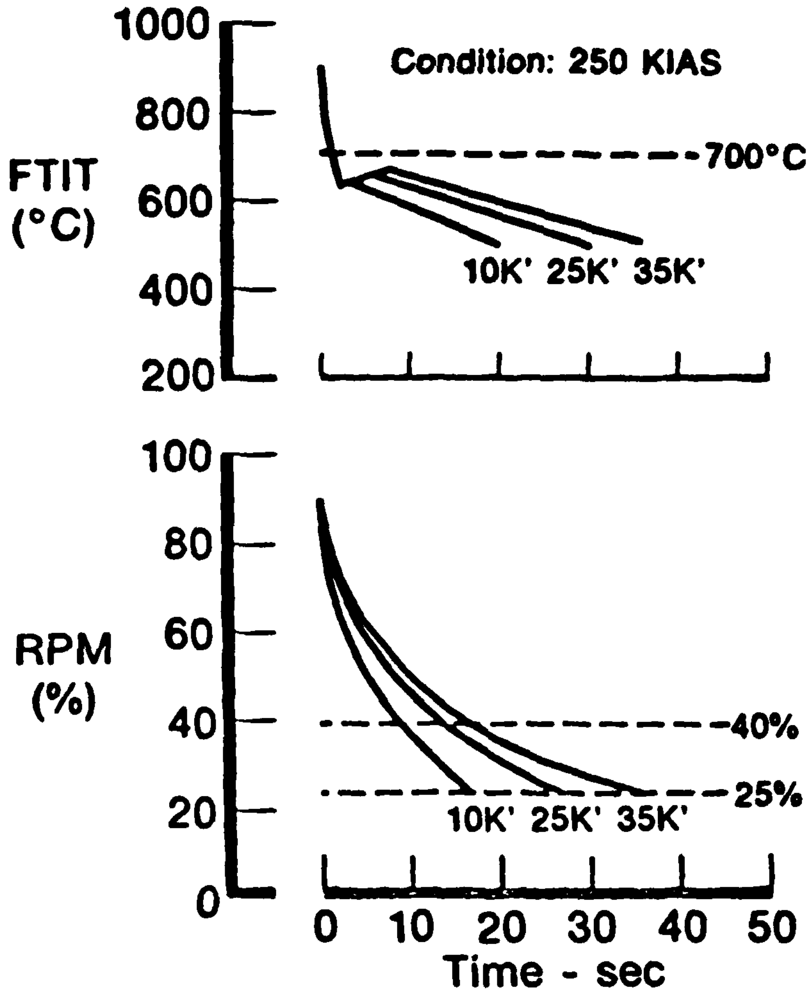


FIGURE 14

EFFECT OF ALTITUDE ON AIRSTARTING

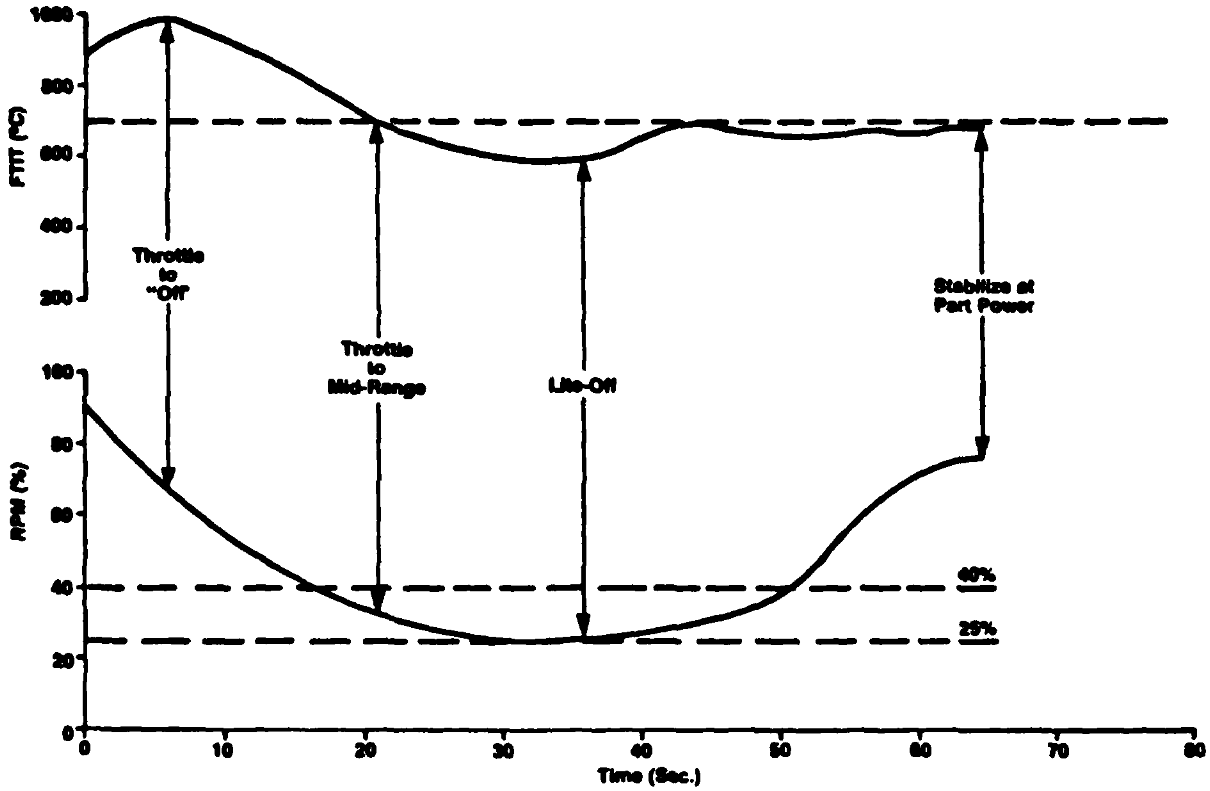


FIGURE 15

HIGH POWER STAGNATION AIRSTART

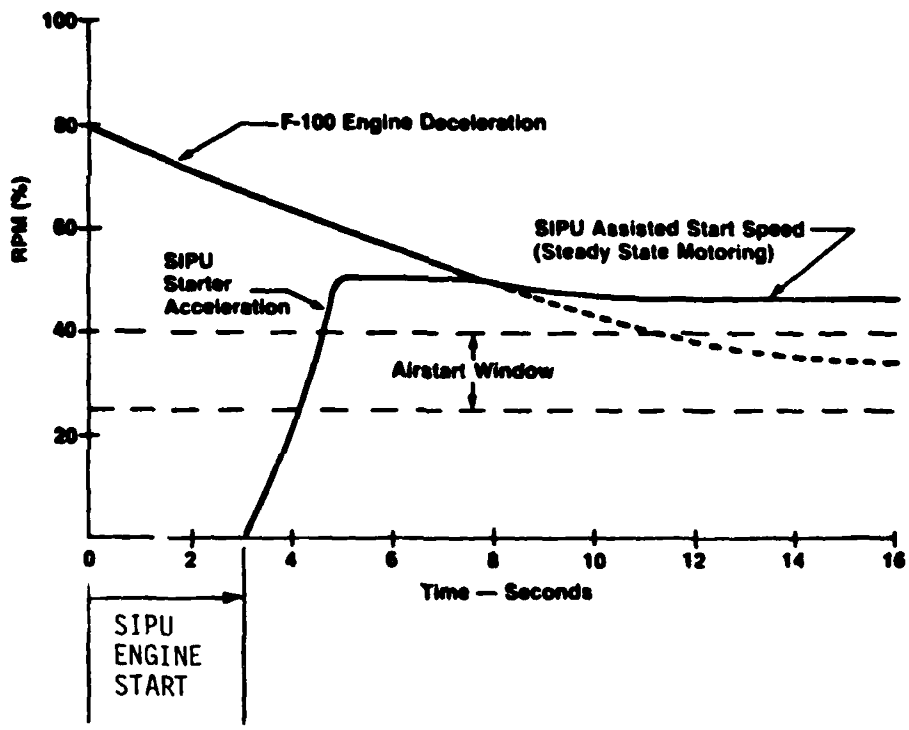


FIGURE 16

ENGINE MOTORING WITH SIPU ASSIST

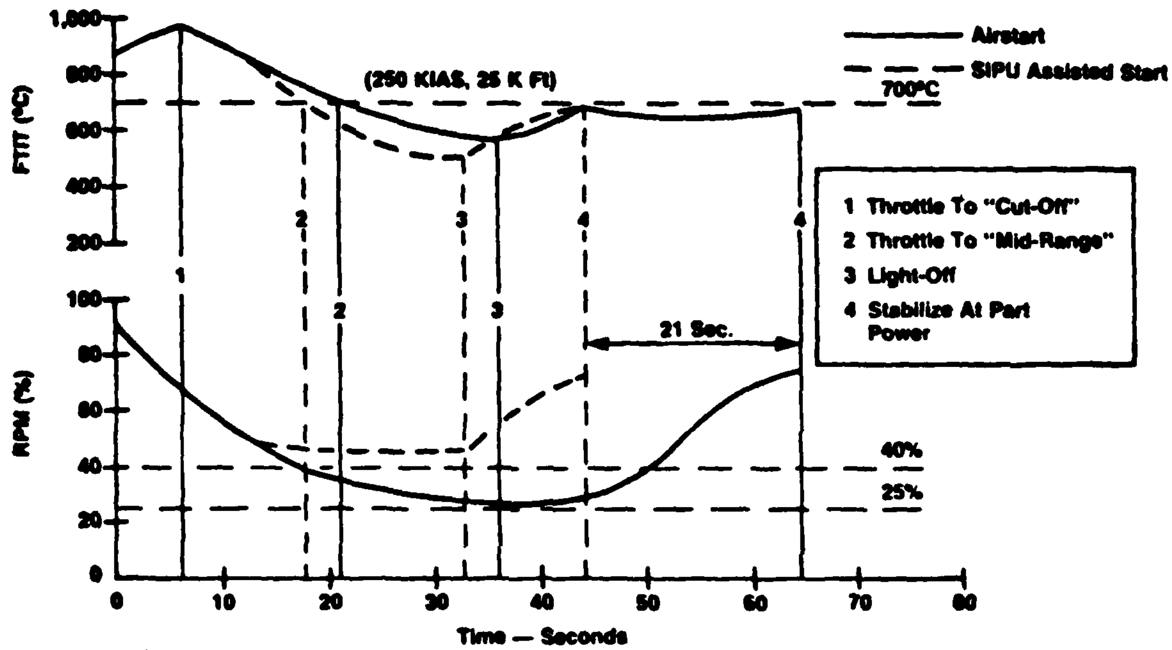


FIGURE 17

SIPU/AIRSTART - START COMPARISON - HIGH POWER STAGNATION

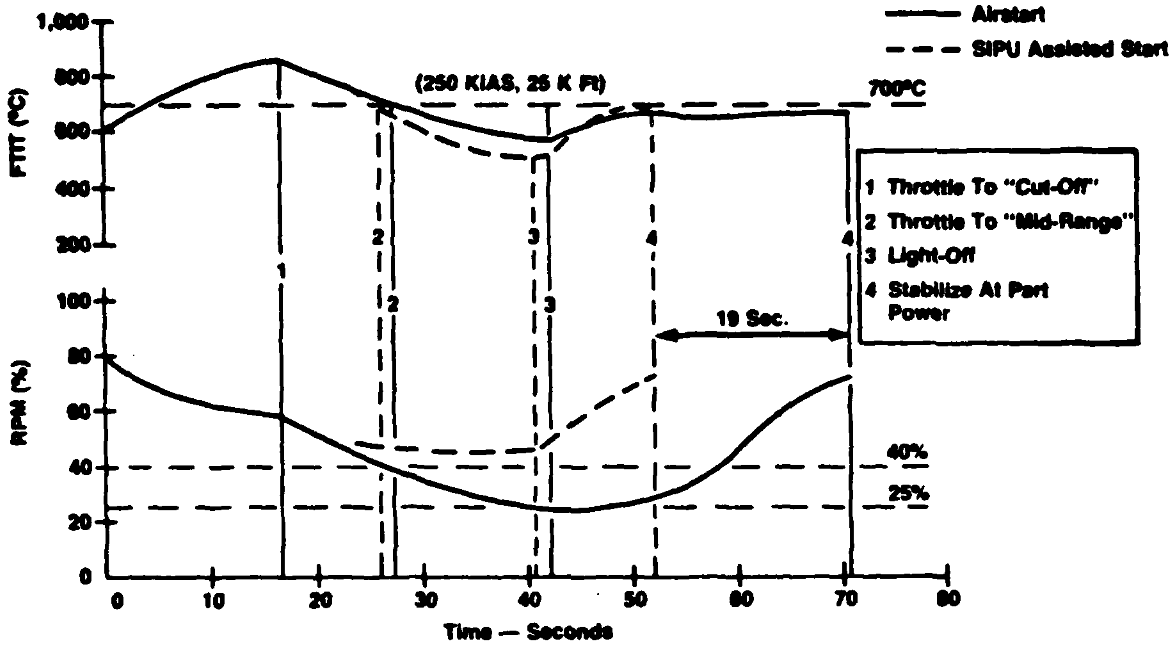


FIGURE 18

SIPU/AIRSTART - START COMPARISON - LOW POWER STAGNATION

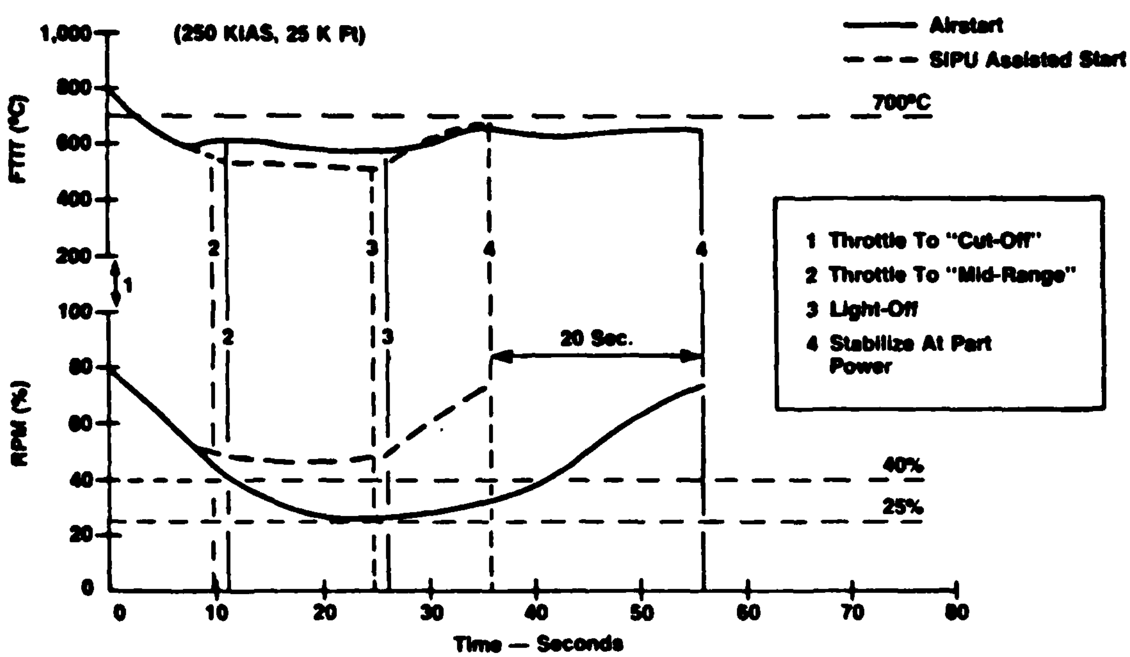


FIGURE 19

SIPU/AIRSTART - START COMPARISON - FLAMEOUT

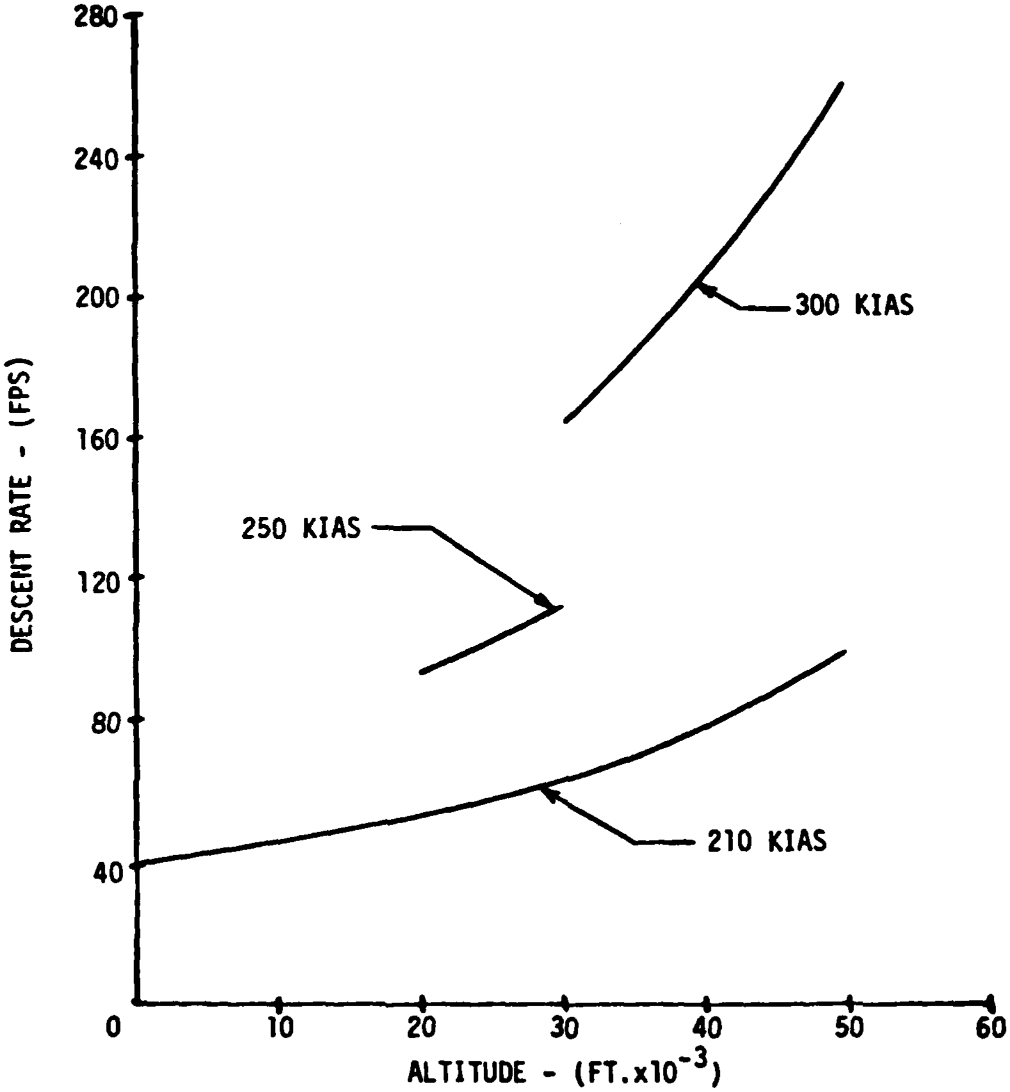
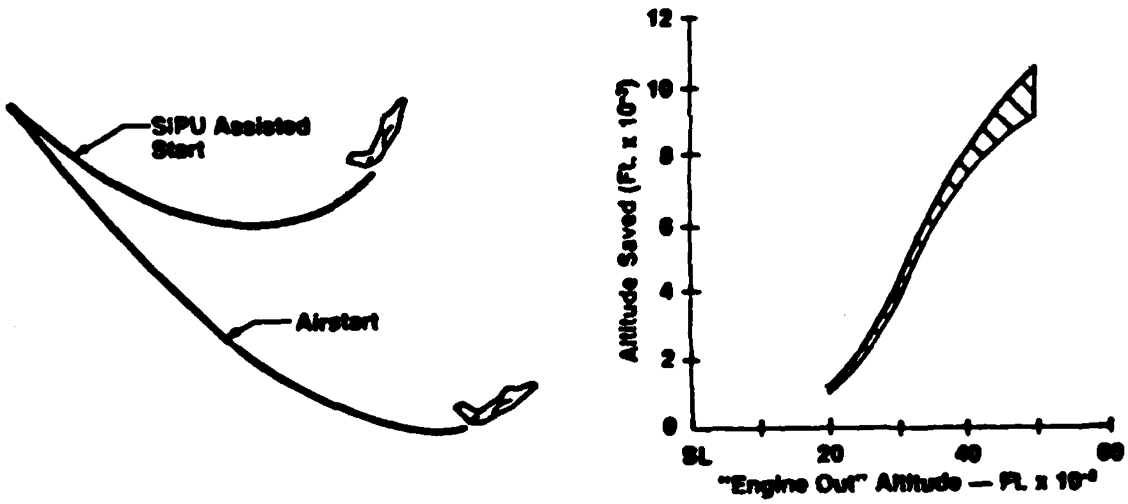


FIGURE 20

DESCENT RATES AT VARIOUS ALTITUDES AND AIRSPEEDS (F-16)



NOTE: BANDWIDTH IS CAUSED BY THE DIFFERENCE IN START TIMES AFTER VARIOUS ENGINE MALFUNCTIONS

FIGURE 21

ALTITUDE SAVED WITH SIPU START ASSIST

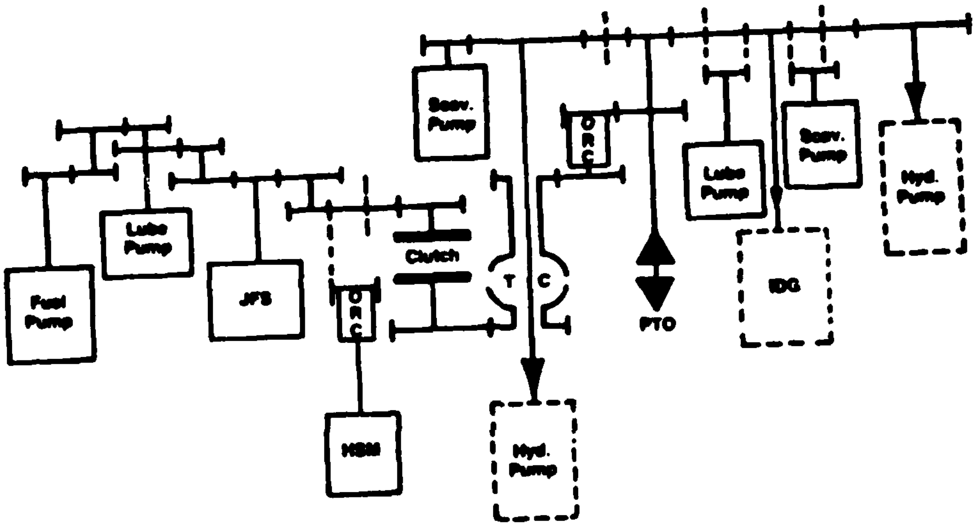


FIGURE 22

F-16 ESS MECHANICAL ARRANGEMENT

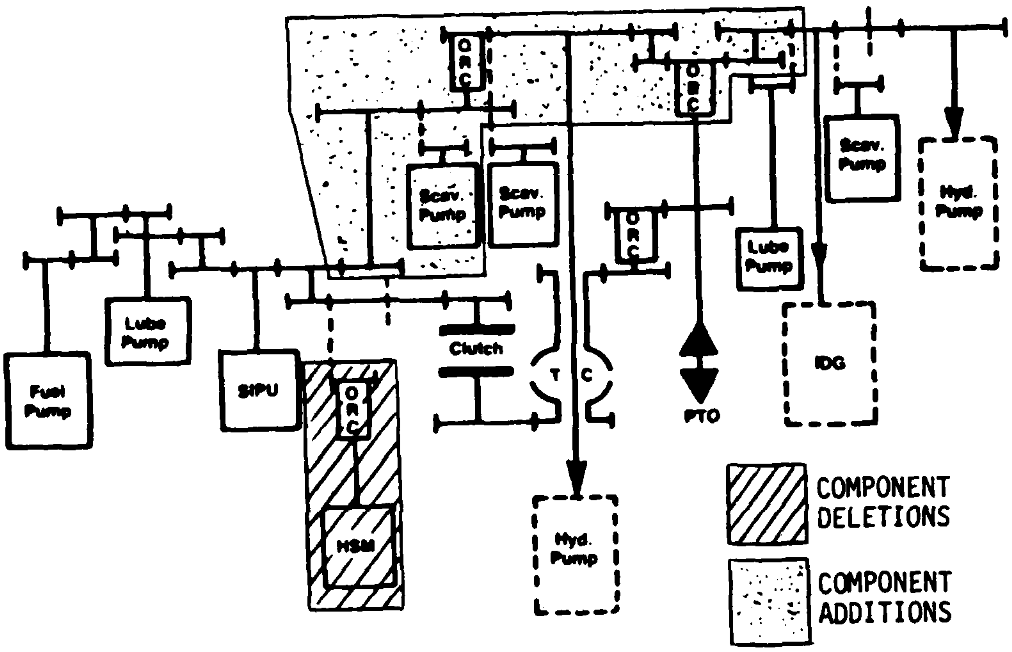


FIGURE 23

ESS MODIFICATIONS FOR SIPU